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Low profile, circularly polarized antenna design for 918 MHZ.

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LOW PROFILE, CIRCULARLY POLARIZED
ANTENNA DESIGN FOR 918 MHZ.

Trent Coleman Mulkern

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

LOW PROFILE, CIRCULARLY POLARIZED ANTENNA
DESIGN FOR 918 MHZ

by

Trent C. Mulkern

June 1978

Thesis Advisor: O. M. Baycura

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The U. S. Army's Range Measuring System (RMS) B unit uses an omnidirectional, quarterwave monopole antenna (Beanie) mounted on a helmet for the transfer of range information. The system has demonstrated a general unreliability in successfully establishing two-way communications between the central computer processor and the field units. One possible reason for this unreliability is the hilly terrain and questionable antenna

performance (gain and coverage) at the test area.
A circularly polarized, low profile antenna was examined be- e
cause of its high gain (6-9db), small size and low cost. A
test model was fabricated to evaluate the performance of this
design compared to the Beanie antenna. Experimental results
of the test model supported the theory. Alternative antenna
designs and materials are suggested for further study.

LOW PROFILE, CIRCULARLY POLARIZED ANTENNA DESIGN FOR 918 MHZ

by

Trent Coleman Mulkern
Lieutenant, United States Navy
B.S.N.E., North Carolina State University, 1971

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

June 1978

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the performance of this design compared to the Beanie
antenna. Experimental results of the test model
supported the theory. Alternative antenna designs and
materials are suggested for further study.

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I. INTRODUCTION

A. BACKGROUND

References 1 and 2 describe the general operation and function of the U. S. Army's Range Measurement System (RMS) and its associated equipment. The RMS system is a non-tactical system which transfers ranging and digital (with the proper input/output devices) information between a central computer and a corresponding transponder Micro-B unit located in the field. The purpose of this system is to evaluate field tactics and the most efficient deployment of men, vehicles, and aircraft in a simulated battle scenario.

Figure 1 presents a basic block diagram of the RMS operation. The C station is located where there is power available and a direct line-cf-sight transmission to A and D stations. The A and D stations are relay sites usually located at fixed geographical locations . The C station receives parallel output commands from the computer and converts them to serial form for output to the field units. The commands will be either ranging or digital communications, and are coded with the respective D,A, and B station address. The B unit response travels the same path back to the C station. The software utilized with the computer dictates the real-time exercise that takes place, and which B unit is interrogated and how often.

The transmissions can follow a C-D-A-B or a C-A-B path, with a maximum path length of 18 kilometers. The system
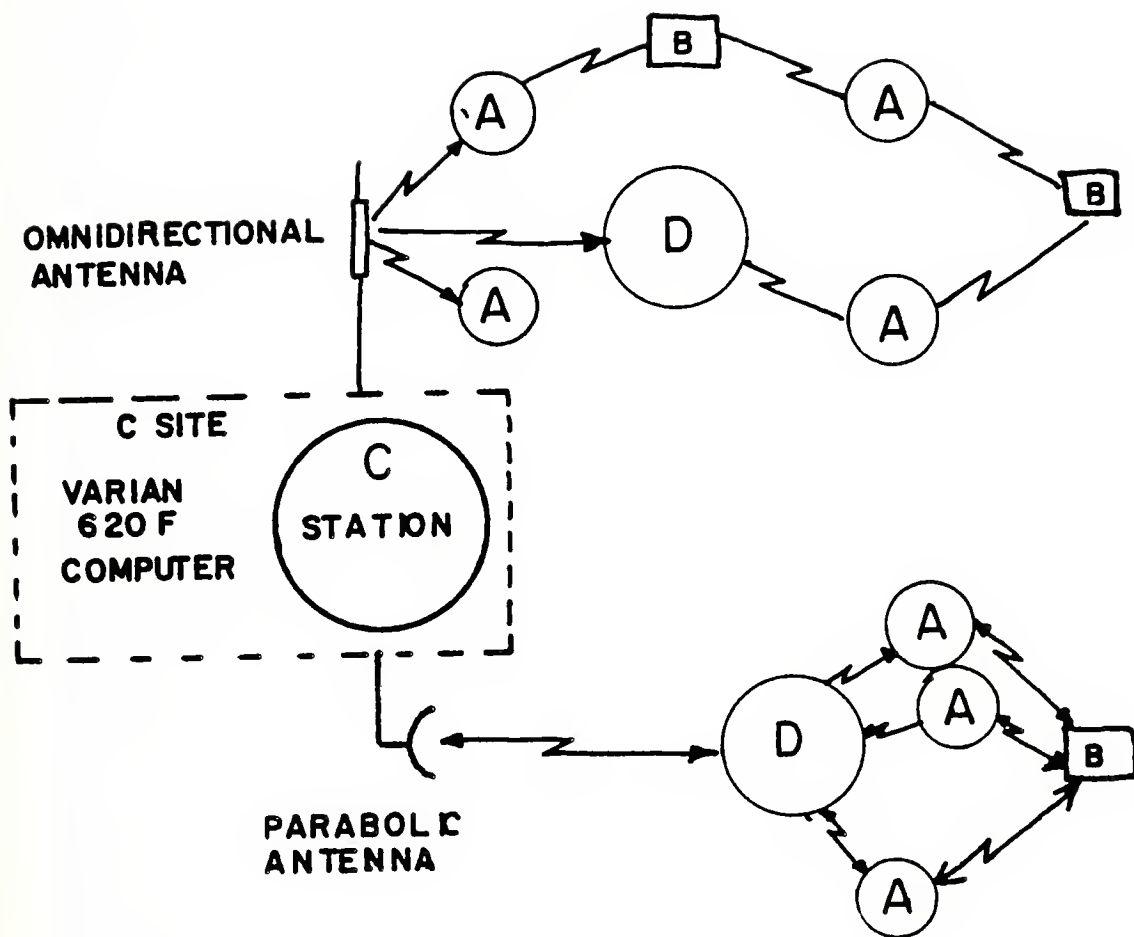
Figure 1 - RMS OPERATION

has the capability of addressing 7 D stations, 127 A stations, and 1,023 B units. The operating frequency is 918 (±7.5) MHz with the transmitter and the receiver operating on one of two channels assigned to each mode of operation (Xmtr-ch. 1, 1.35 MHz, ch. 4, 4.05 MHz; Rcvr- ch. 2, 2.25 MHz, ch. 3, 3.15 MHz). The purpose of the separate channels is to reduce interference.

B. PROBLEM DISCRIPTION

Numerous operational problems have plagued the RMS system at its field location at Fort Hunter Liggett, California Changes in the computer software have caused saturation problems in data processing. This together with a failure of B units has reduced the maximum number of operational field units from 1000 to 10. The area of field evaluation has the A and D stations located on the top of hills in order to communicate with the C station and the B units located in opposing valleys. This poses interesting propagation problems with the A and D station antenna patterns not being depressed enough to see the playing units. Reference 3 describes the problems encountered in equipment reliability and describes ranging errors in excess of 100 yards.

The problem areas under investigation have been divided into the following areas: (1) Multipath propagation errors, (2) Heat degradation of B units, (3) Software, (4) Equipment maintenance and alignment, and (5) Excessive propagation losses peculiar to the test evaluation site.

II. BEANIE ANTENNA

A. DISCRIPTION AND THEORY

Figure 2 describes the physical shape and size cf the
helmet mounted Beanie antenna. It is a quarter-wave,
monopole antenna connected to a mesh screen ground plane of
spherical shape to conform to an army helmet. A short
length of 50 ohm RG-58C/U cable connects the antenna to the
SMA connector located on the edge of the ground plane.
Another length of cable connects the antenna unit to the
micro-B unit. The entire antenna and grcund plane are
protected with a coating of rubber material to prevent
damage to the unit under field conditions.

Reference 4 states that the ability cf an antenna to
concentrate the radiated power (or received power) in a
given direction, is specified in terms of antenna gain,
power gain, directive gain (or directivity), and antenna
efficiency. Directive gain is defined as the ratio of the
radiation intensity in a direction to the average power
radiated.

$$g_d = \frac{4 \Phi (\theta, \phi) \pi}{\int \Phi \, d\Omega}$$

$$\Phi (\theta, \phi) \sim watts/unit \ solid \ angle$$

$$G_d = 10 LOG \ g_d$$

The directivity cf an antenna is defined as its maximum
directive gain in a specific direction (angle). Directivity

QUARTER WAVE
MONOPOLE ANTENNA

RG-58CIU CABLE

SMA CONNECTOR

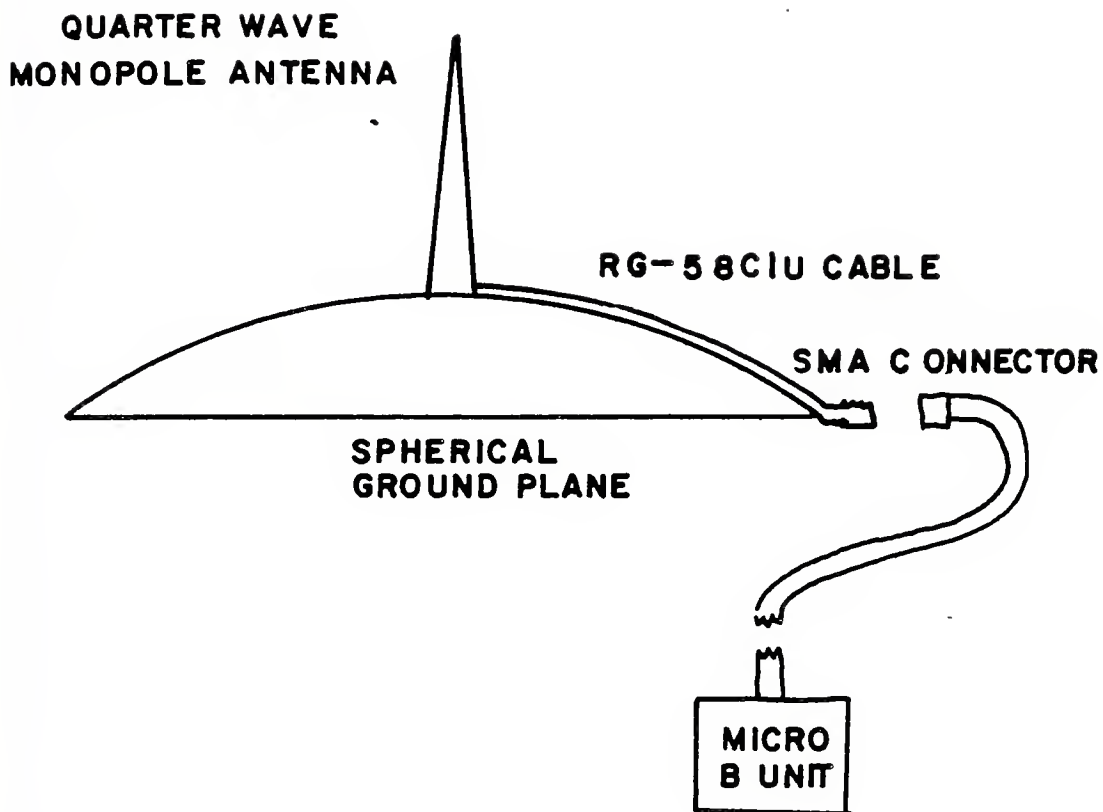SPHERICAL
GROUND PLANE

MICRO
B UNIT

Figure 2 - BEANIE ANTENNA

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and directive gain are sometimes used interchangeably. Reference 5 states that the directive gain for an antenna beam can also be shown to be:

$$g_d = \frac{41,253}{\Theta_b \, \phi_b}$$

where Θ_b and ϕ_b are the half power beam widths measured in degrees.

Power gain is defined as the ratio of the radiation intensity divided by the total input power.

$$g_p = \frac{4 \pi \, \Phi}{W_t}$$

$W_t = W_r + W_l = $ total input power

$W_l = $ ohmic losses

$W_r = $ antenna radiation losses

For antennas having 100 percent efficiency, directive gain equals power gain [Ref. 4].

Antenna efficiency, rho [Ref. 4], is defined as the power gain divided by the directive gain. Antenna theory dictates that a quarter-wave monopole, having 100 percent efficiency should have an omnidirectional field pattern; and it should have a maximum directive gain of 1.76 db (assuming 100 percent of the available power is transferred to the load).

$$\rho \, (\text{efficiency}) = \frac{100 \, g_p}{g_d}$$

B. ANTENNA EVALUATION

The evaluation of the Beanie antenna is divided into two sections. The first section involves experimental evaluation of the antenna and its associated cables using the Vector

Voltmeter Experiment described in Figure 3. The second step in the evaluation process is to take radiation patterns of the Beanie antenna to determine its directive gain compared with known theoretical results.

The Vector Voltmeter experiment evaluates the performance of an antenna system by measuring its standing wave ratio (SWR). A voltage SWR (VSWR) of 1 indicates a perfect impedance match at a particular frequency, whereas a VSWR greater than one indicates reflected power from the antenna due to an imperfect impedance match at the desired frequency.

The antenna radiation pattern range and the associated equipment are described in Figures 4 and 5. Vertically and horizontally polarized field patterns were made using an A-station monopole antenna as the reference transmitting antenna. These E field patterns were used as the basis for evaluation of antenna gain, and were also used as an evaluation standard applied to the design performance of the low profile antenna design. It should be noted at this point that several months of experimentation involved the use of a NEMS Clark 2000-A and extension unit REU-300B receiver. The equipment frequency range (910 mhz maximum) was not sufficient to cover the frequency range under investigation (911.5 to 925.5 mhz). Possible nonlinearities in this extended frequency region makes the radiation pattern gains taken at different times somewhat suspect. A receiver was purchased later that covered the frequency range, but do to its poorer sensitivity the test signal generators used had to be operated at their maximum power performance. This led to more possible antenna gain nonlinearities which meant that the antenna patterns had to be taken in sets for the proper comparison of data taken under similar test conditions.
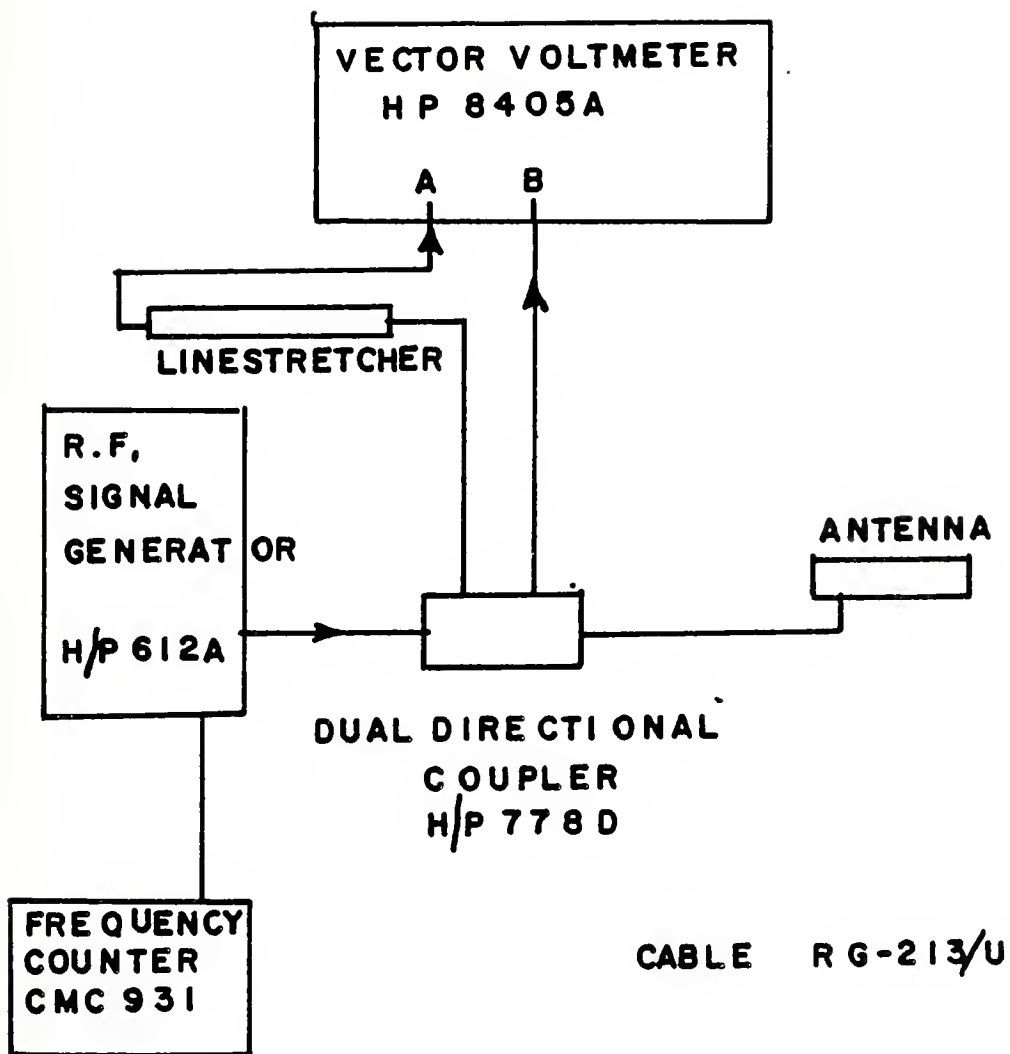
Figure 3 — VECTOR VOLTMETER EQUIPMENT SETUP

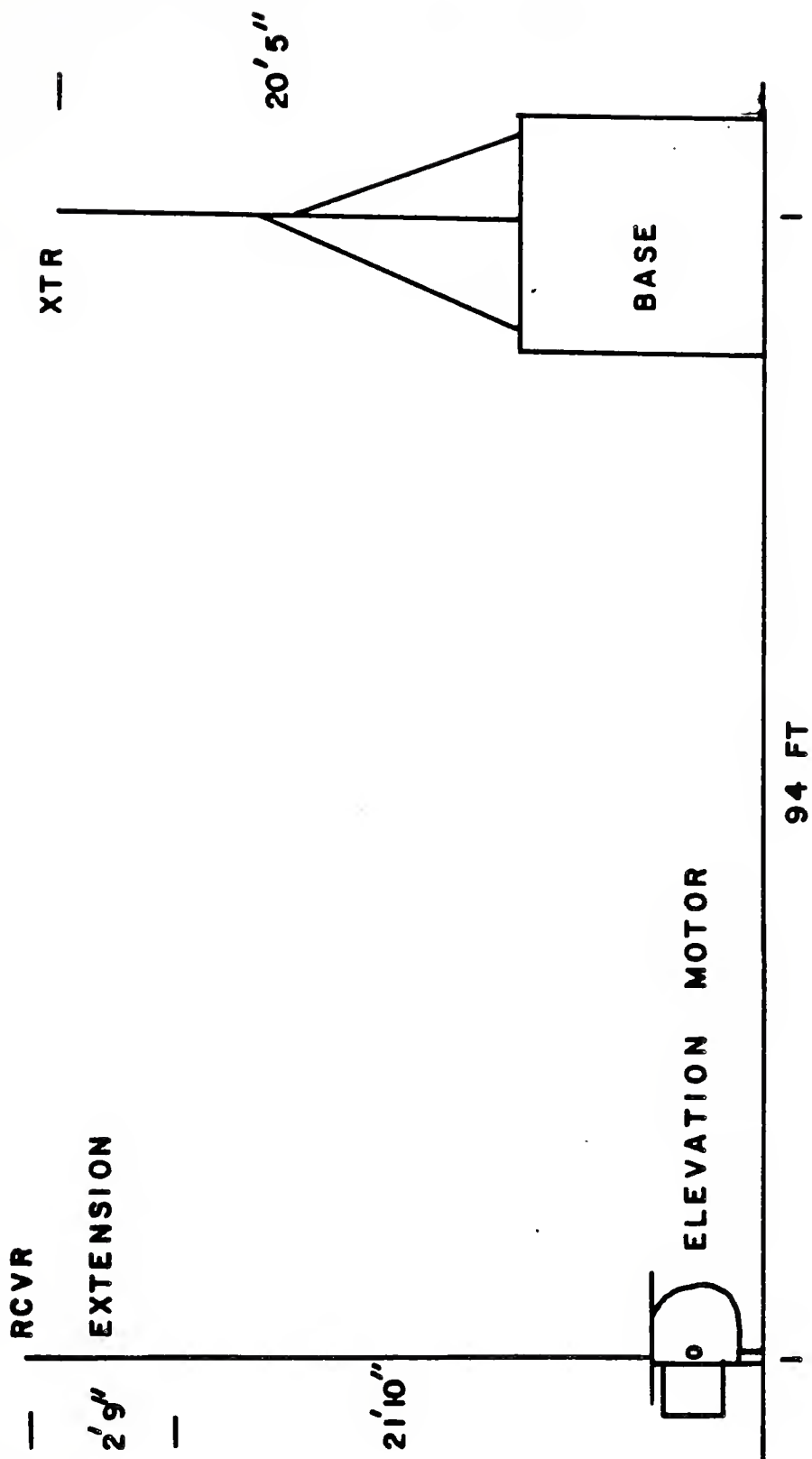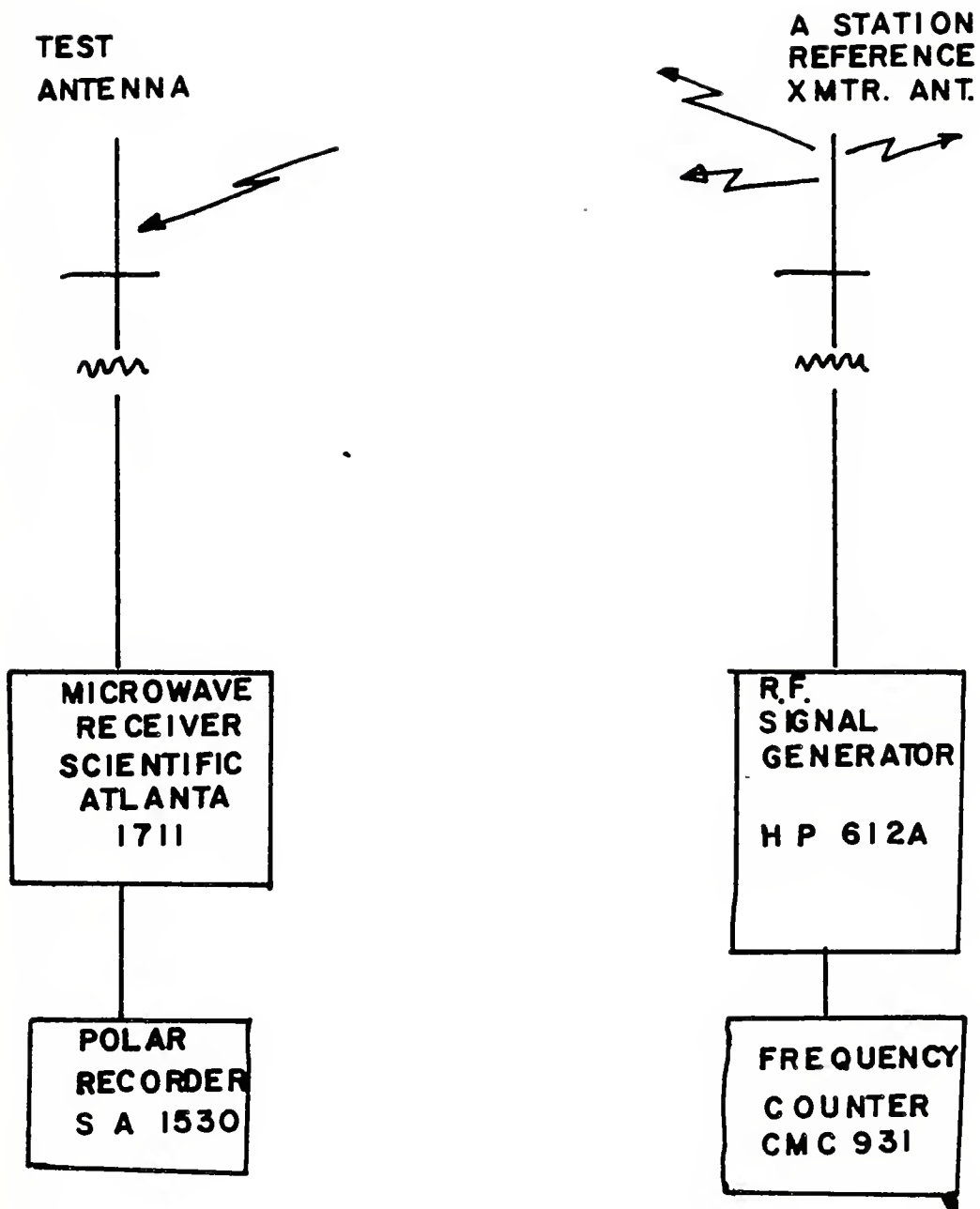Figure 4 — ANTENNA RANGE CONFIGURATION

TEST
ANTENNA

A STATION
REFERENCE
X MTR. ANT.

MICROWAVE
RECEIVER
SCIENTIFIC
ATLANTA
1711

R.F.
SIGNAL
GENERATOR

HP 612A

POLAR
RECORDER
S A 1530

FREQUENCY
COUNTER
CMC 931

Figure 5 –   ANTENNA RANGE EQUIPMENT SETUP

C. EXPERIMENTAL RESULTS

The comparison of antenna performance will be based primarily on three experimental results. The Vector Voltmeter Experiment will determine real losses in matching over the frequency bandwidth of 16 MHz. The radiation patterns taken will yield directive gain, and overall azimuth and elevation coverage. Antenna pattern coverage is important to the antenna evaluation process because of the terrain encountered in actual RMS performance.

Figure 6 shows the tabulated results from a Vector Voltmeter Experiment performed on the Beanie antenna. As shown by the results, the Beanie antenna has a fairly consistent VSWR and phase angle, PHI, over the frequency range in question. An average VSWR of 1.30 converts to a 1.14 db power loss. Most of this loss is in cable losses and a mismatch of cable resistance to the radiation resistance exhibited by the antenna. Radiation resistance is defined for a short monopole antenna from Reference 4 below (note: cable losses are minimal and have little effect).

$$R_{rad} = 40 \ \pi^2 \left(\frac{h}{\lambda}\right)^2$$
$$= 40 \ \pi^2 \left(\frac{1}{4}\right)^2$$
$$= 24.67 \ \text{ohms}$$

Conductor losses in the antenna are calculated below.

$$R_{cl} = \frac{R_s \ l}{3 \pi \ a} = 0.2 \ \text{ohms}$$

$l \sim$ antenna length

$a \sim$ antenna diameter

The variance in phase angle is fairly consistent, and only varies 27 degrees over the bandwidth. Phase angle is

FREQ (MHz)	K_r	VSWR	ϕ
908	0.132	1.30	$-5°$
910	0.126	1.28	$+1°$
912	0.131	1.30	$+9°$
914	0.125	1.28	$+9°$
916	0.123	1.28	$+12°$
918	0.131	1.30	$+16°$
920	0.135	1.31	$+22°$
922	0.159	1.38	$+34°$
923	0.162	1.38	$+36°$

K_r - REFLECTION COEFFICIENT
ϕ - PHASE ANGLE

Figure 6 — BEANIE VECTOR VOLTMETER EXPERIMENT RESULTS

important in this experiment since the Micro-B unit maybe interrogated by more than one A station at a time. This could lead to a phase shift in the received signal making it unreadable , thus yielding no response.

RG-58C/U cable used with the Beanie antenna was found to exhibit a resistance of 45 ohms at a frequency of 918 mhz. This resistance reading was found using the standard method of calculating cable resistance described in Reference 6. Now using the formula for the voltage reflection coefficient described below from Reference 7;

$$K_r = \frac{R_{rad} - R_o}{R_{rad} + R_o}$$

$$= \frac{24.67 - 43}{67.67}$$

$$= -0.270$$

the transmission coefficient is equal to one minus the reflection coefficient, or 0.73. The expected theoretical gain of this antenna is equal to the transmission coefficient times the maximum theoretical gain (1.5), or 1.096 (0.398 db).

Figures 7 and 8 show the far field azimuth and elevation patterns of the Beanie antenna. It is noted here that there is an obvious variance from the omnidirectional pattern predicted from theory in the azimuth pattern. Similar patterns were taken throughout a three month period and similar results were obtained . The reasons for this variance could be that the Beanie antenna was never actually vertical with the transmitting antenna, or it is possible that the feed system located on the periphery of the ground plane could be having some effect on the radiation pattern.
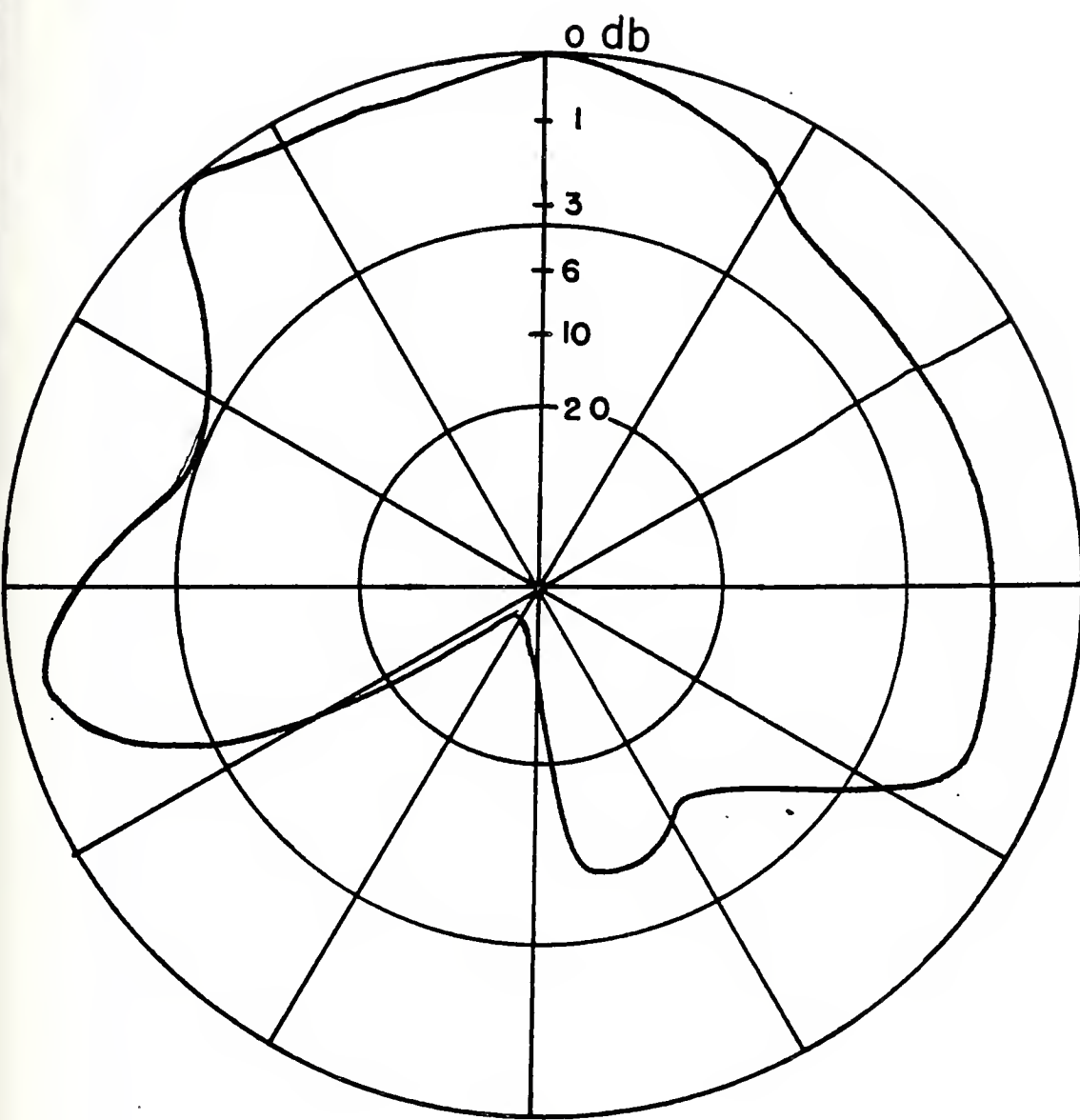
o db

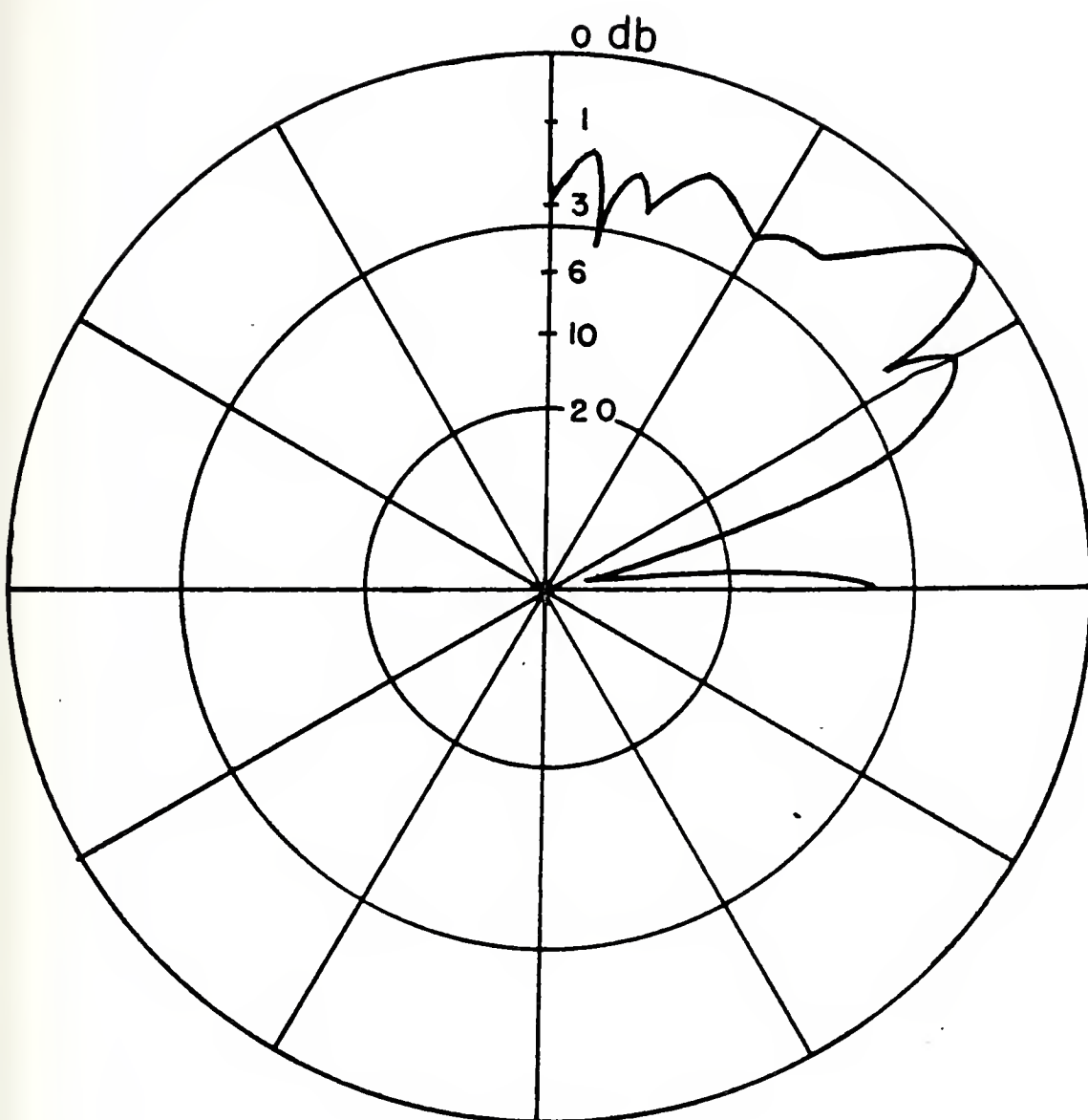Figure 7 - BEANIE FAR FIELD AZIMUTH RADIATION PATTERN

20

Figure 8 -   BEANIE FAR FIELD ELEVATION RADIATION PATTERN

21

The half power beamwidth in the azimuth direction measures 237 degrees.

The far field elevation pattern shows a half power beamwidth of 120 degrees. Figure 8 shows how the directive gain of the antenna decreases as the antenna is rotated 90 degrees. This shows that the response of a vertically polarized antenna to a horizontally polarized signal is very low. This position (rotated 90 degrees from the vertical) would approximate the soldier in a prone position that he might take in an actual field exercise. The reduced gain plus the cancellation caused by multipath effects will cause the Micro-B unit to fail to receive a range command from an interrogating A station.

The maximum directive gain was found to be equal to 1.450, or 1.61 db, using the measured half-power beam widths from figures 7 and 8. The actual gain is the maximum directive gain times the efficiency (0.73) which equals 1.058 (0.25 db). This corresponds to a 3.6 percent error over the theoretical gain calculated earlier.

The theory used in this section compares very favorably with the experimental results obtained. It is concluded, that although the Beanie antenna is low cost and simplistic in design, the 1.51 db loss in gain, together with poor azimuth and elevation radiation patterns, combine to make the quarter wave monopole a contributing factor in the poor performance of the RMS system. These results form the basis for further investigation of a substitute antenna system for the Beanie antenna.

III. LOW PROFILE, LINEARLY POLARIZED ANTENNA DESIGN

A. INTRODUCTION

The low profile linearly polarized microstrip antenna was chosen for its small size, high gain, simple design, and low cost. This type of antenna has found many applications involving aircraft, spacecraft, and missiles where size and weight are constraints. These antennas are constructed on a thin (with thickness very much less than the wavelength) dielectric material that has copper bonded to both sides. One side forms the ground plane. The opposite side forms the antenna element which is formed into any shape by etching the unused copper off of the dielectric surface. The elements can be fed from multiple feed points. Inductive and/or capacitive elements may also be etched into the surface to minimize the reflection coeficient by forming a hybrid matching network on the dielectric surface.

From Reference 8, the unique characteristics of microstrip antennas are as follows: (1) They are very thin and need not extend very far below or above the ground plane, and consequently can be made very rugged, (2) They are economical to construct and design, (3) Either linear or circular polarization is possible, (4) Dual frequency antennas are possible, and (5) They are easy to mount on existing structures (paste on antennas with a hole from the ground side are conceivable). Antennas have been designed for frequencies up to Ku band (up to 18 Gigahertz). The lower end of the frequency spectrum (below L band) causes

the antenna element size to increase beyound manageable proportions. The feed network and any solid state components that might be added to the PC board do not interfere with the radiation pattern because they are electrically close to the ground plane, which is the back of the antenna, and because the feed lines are perpindicular to the electric field being emitted by the photo etched radiator.

An example of a microstrip wraparound antenna, from Reference 9, is shown in figure 9. This example shows a multiple feed strip radiator that is fed by copper feed strips. Either a tapered line parallel feed network, or a quarter wave transformer parallel feed network can be used to provide the necessary matching of the radiator to a coaxial line input. This antenna when recessed into the missile bcdy, best suits the aerodynamic flow characteristics of the missile, yet provides a high gain which may be required to allcw for low power telemetry or command and control signals to be received/sent frcm an exterior source where power is a constraint. The low cost of such an antenna can be met because the single printed circuit board antenna is manufactured by the same low-cost photo-etch process used to make electronic circuit boards.

The first design chosen for possible use was a circular microstrip antenna with a grounded short between the radiator and the grcund plane. The feed line is a coaxial feed from the back (ground side) of the antenna, through the dielectric material and terminating on the radiator. Reference 8 describes the antenna design, and figure 10 shows a typical model. This particular model was chosen because it was felt that it could be easily mounted on a standard U. S. Army battle helmet, as shown in figure 11. As will be shcwn later in this paper, this was a poor choice because this manner cf mounting does not take advantage of the maximum EM lines of force as shown by figure 12.
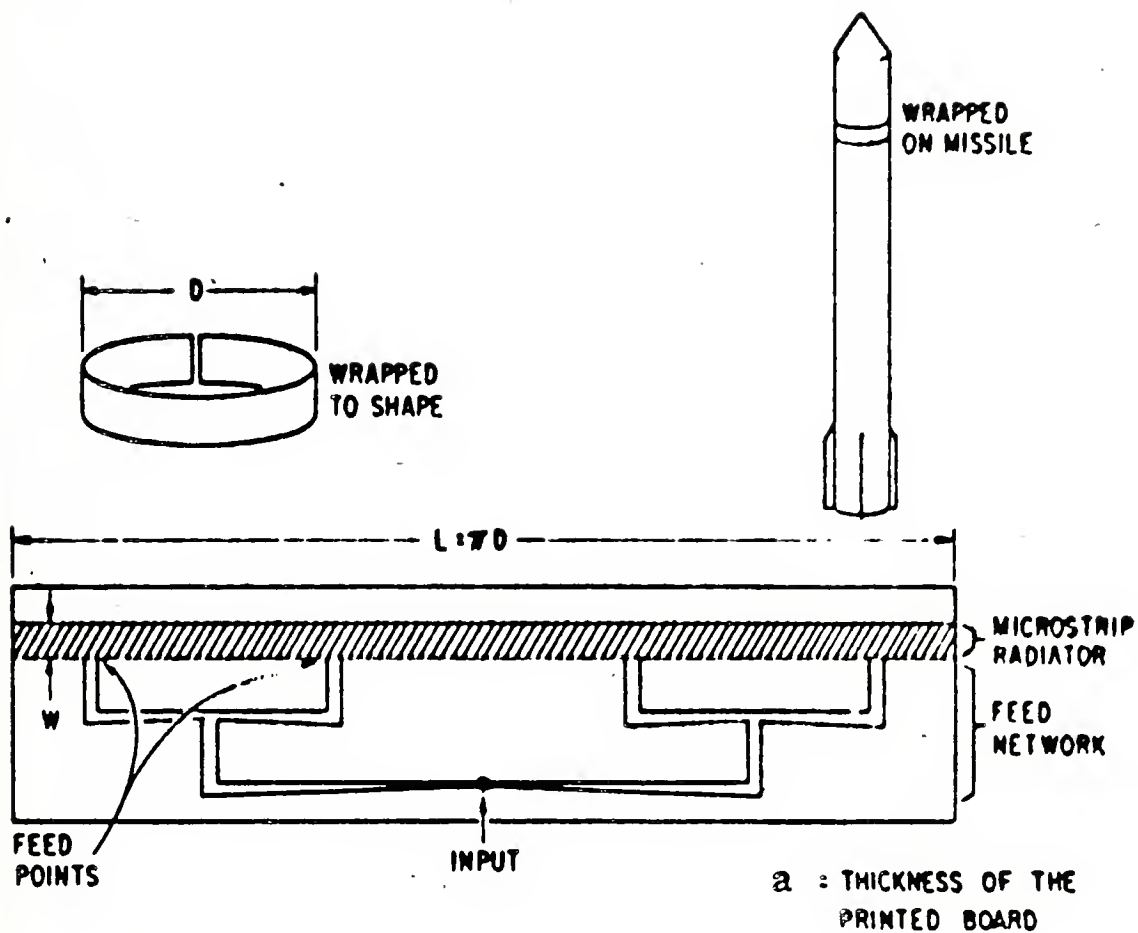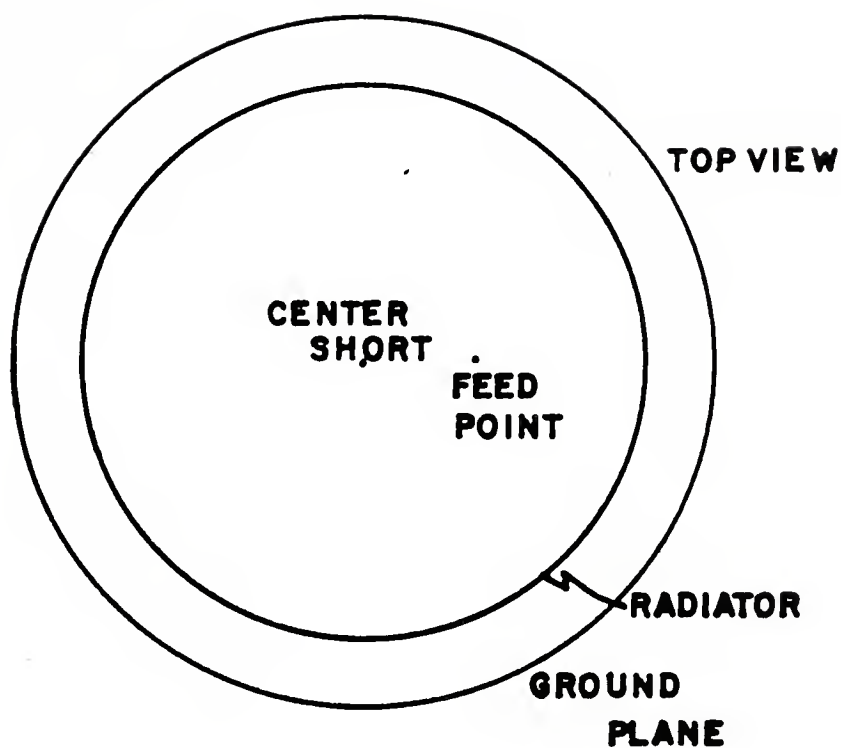
Figure 9 -   MICROSTRIP WRAPAROUND ANTENNA

TOP VIEW

CENTER
SHORT
FEED
POINT

RADIATOR

GROUND
PLANE

SIDE VIEW EXPANDED

FEED POINT   RADIATOR

DIELECTRIC
MATERIAL

GROUND
PLANE   CENTER
              SHORT

SMA CONNECTOR

RG-58C/U

CABLE
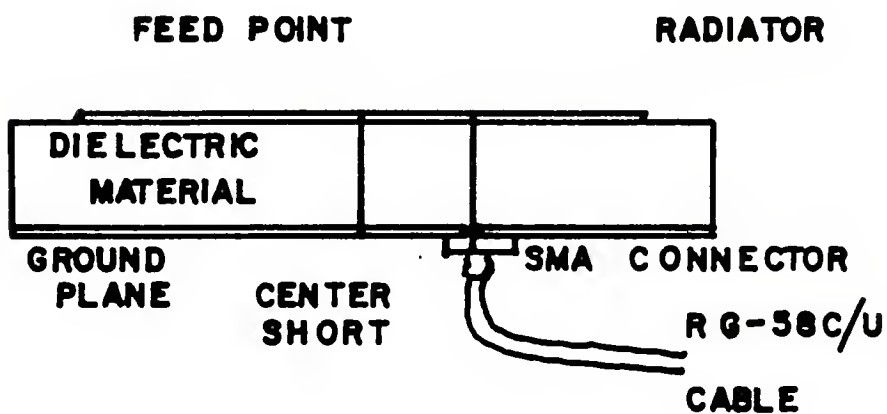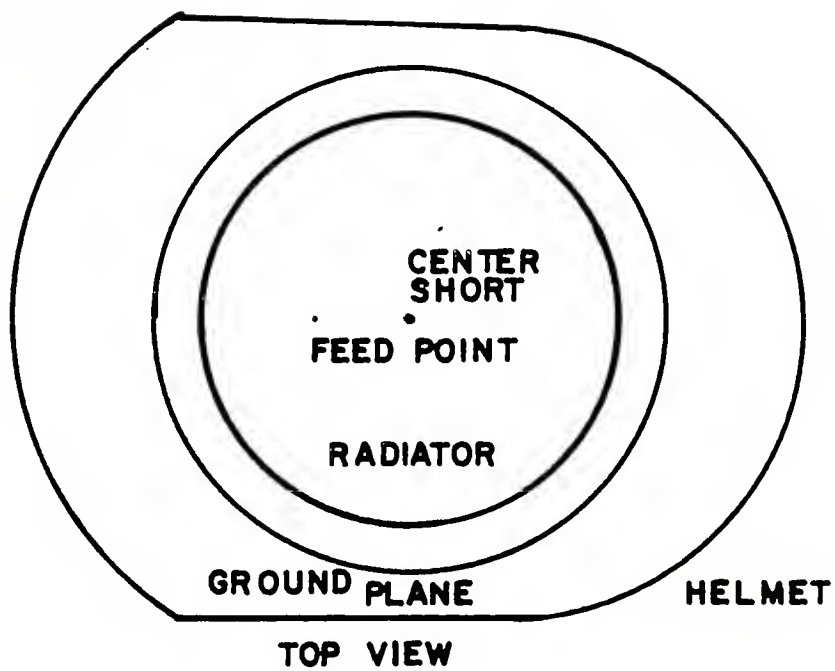
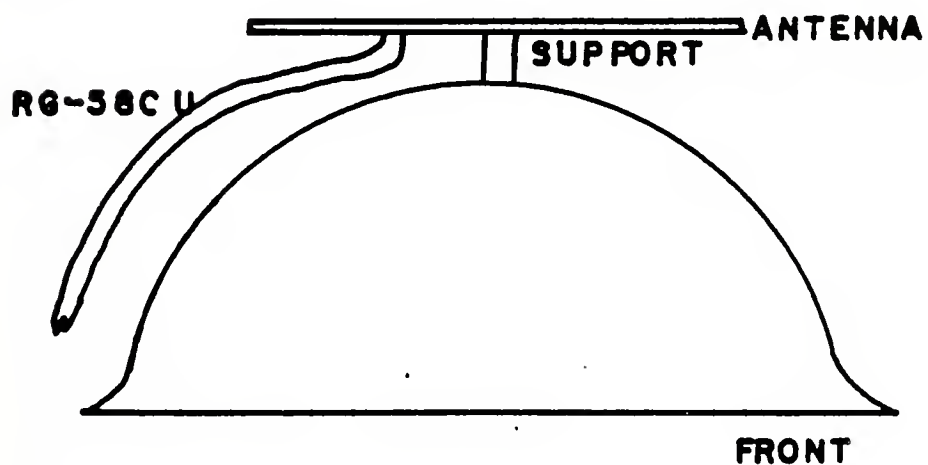Figure 10 - CIRCULAR MICROSTRIP DESIGN

Figure 11 - PROPOSED HELMET MOUNTING
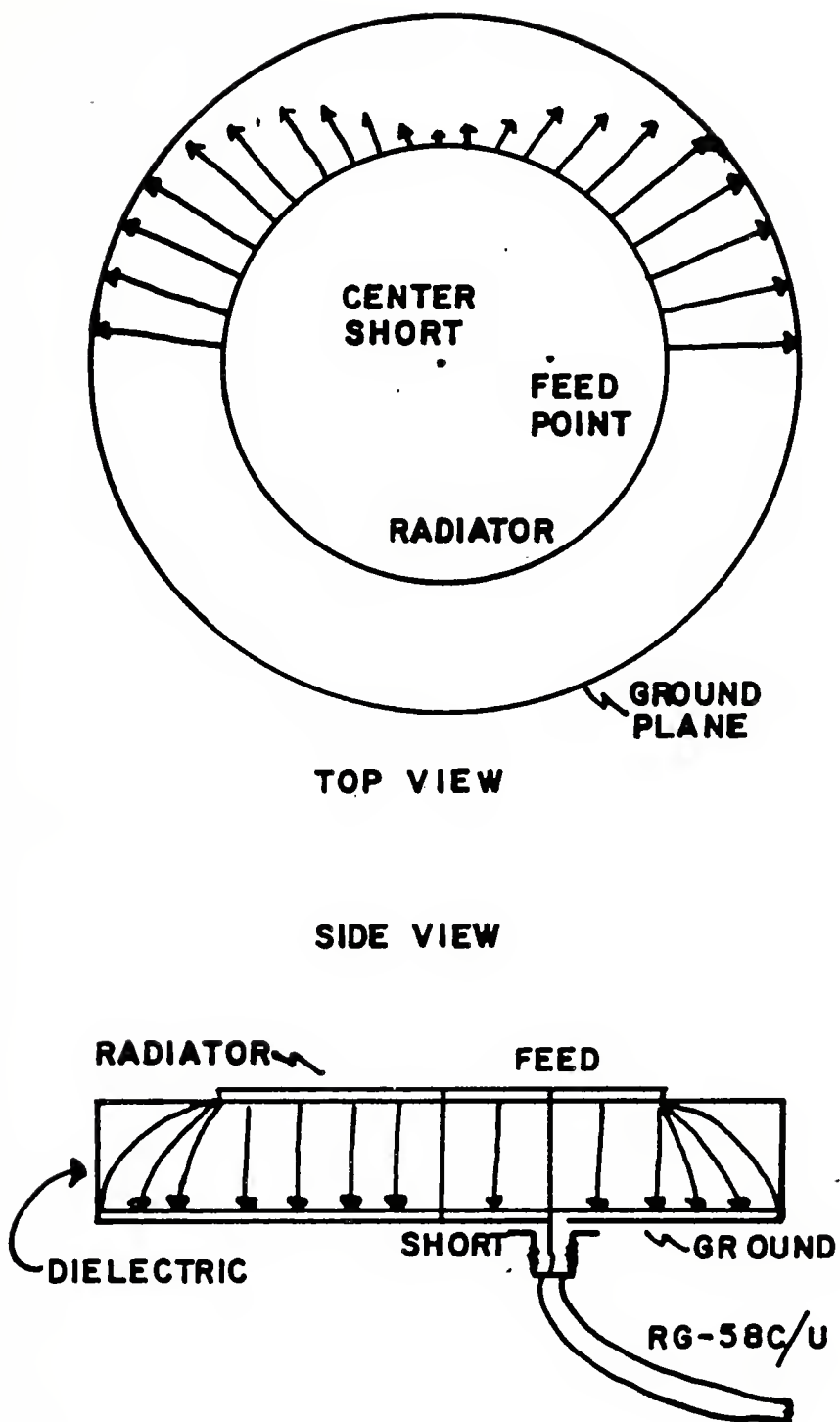
TOP VIEW

SIDE VIEW

Figure 12 - E-FIELD LINES OF FORCE

Reference 8 also describes the high gain features of this type of antenna as being four to seven db above isotropic. As will be shown later in this paper, this advertised feature is incorrect for the model described. High gains can be achieved, but the size of the antenna required is much larger than described in the article. A literature search was conducted on this antenna design, but little published theory exists which accurately describes the theory, or formulas to be used in the design of microstrip antennas. Therefore a secondary objective of this paper will be to develop an orderly, theoretical approach to designing microstrip antennas; followed by experimental results to support the theory and conclusions formed.

B. ANTENNA DESIGN AND THEORY

The initial antenna was fabricated from Micaply copper cladded printed circuit board. The dielectric material is one sixteenth of an inch thick with a dielectric constant of 4.8 measured at a frequency of 2 gigahertz. The radiating element size was determined to be 1.72 inches in radius from the below formula obtained from Reference 8 and derived from Reference 10.

$$F = \frac{1.841 C}{2 \pi a (\epsilon_r)^{1/2}}$$

F ~ frequency 918MHz   a ~ antenna radius
C ~ speed of light ϵ_r ~ relative dielectric
                                    constant

The factor of 1.841 corresponds to the first zero of the derivative of the Bessel function of the first order exhibited by the quarter-wave cavity created when a center

29

short is added to the PC board. Reference 8 also suggests that the feedpoint location should be at a distance about 32 percent of the radius from the center short. The ground plane extension beyond the radiating element was arbitrarily chosen to be 30 percent. Later experiments in this area were done to see the effect of reducing or extending the ground plane about the radiating element.

A literature search to determine a means for measuring the edge impedance of the circular disk by experimental means did not prove fruitful for these frequency ranges. A general relationship for the conductance of a slot radiator whose width approximated a quarter wavelength was obtained from Reference 9 and is shown in figure 13. Since the disk radiator approximates a parallel plate transmission line, each slot of a square/rectangular radiator approximates two similar resistances in parallel with the reactive portions cancelling due to their being 180 degrees out of phase (or at least they are assumed to be very small). Thus the input impedance seen is one half the slot resistance. Since Reference 9 assumes a square/rectangular radiator, the input impedance for a circular disk radiator can be assumed to be somewhat less and the reactive impedances to have a greater value, therefore they will have more effect.

Figure 14 shows the typical estimated impedance behavior of the circular radiator in its most simplistic form. An estimated feed point location of 0.516 inches is established as a starting point to approximate a matched feed, using 45 ohms as the cable resistance calculated earlier (note: this first feed point estimate compares favorably with that mentioned earlier, i.e. 30 percent of the radiator disk radius). A series of Vector Voltmeter experiments was conducted to find which feed point yielded the optimum VSWR. The results of those measurements are shown in figures 15 and 16. The results (and later measurements) show that an

30

$$G_a \approx \frac{\pi}{\lambda_0 \eta} \left[1 - \frac{(\hbar a)^2}{24} \right]$$

$$\lambda_0 = 5.87 \text{ in.}$$
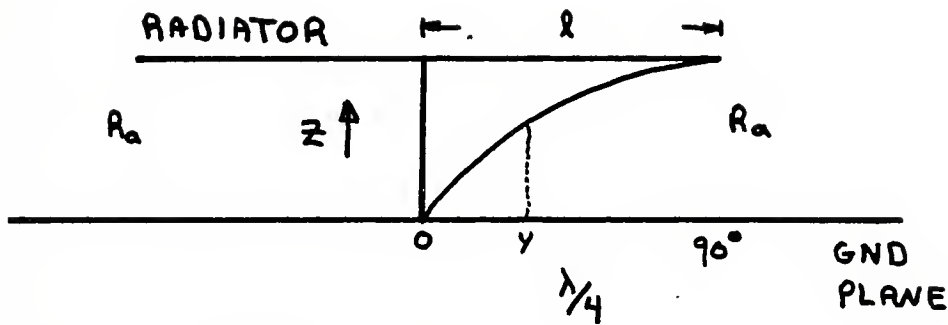
$$\frac{(\hbar a)^2}{24} << 1$$

$$G_a = \frac{\pi}{\lambda_0 \eta} \cdot \frac{1}{120 \lambda_0}$$

$$r_a = \frac{1}{G_a}$$

$$R_a = \frac{r_a}{\ell} = \frac{120 \lambda_0}{\ell}$$

$$R_{in} = \frac{R_a}{2} = \frac{120 \lambda_0}{2\ell} = \frac{60 \lambda_0}{\ell}$$

Figure 13 — ANTENNA IMPEDANCE

$$R_a = \frac{120\lambda_0}{L} = 198.98\,\Omega$$

$$R_{in} = \frac{R_a}{2} = 99.49\,\Omega$$

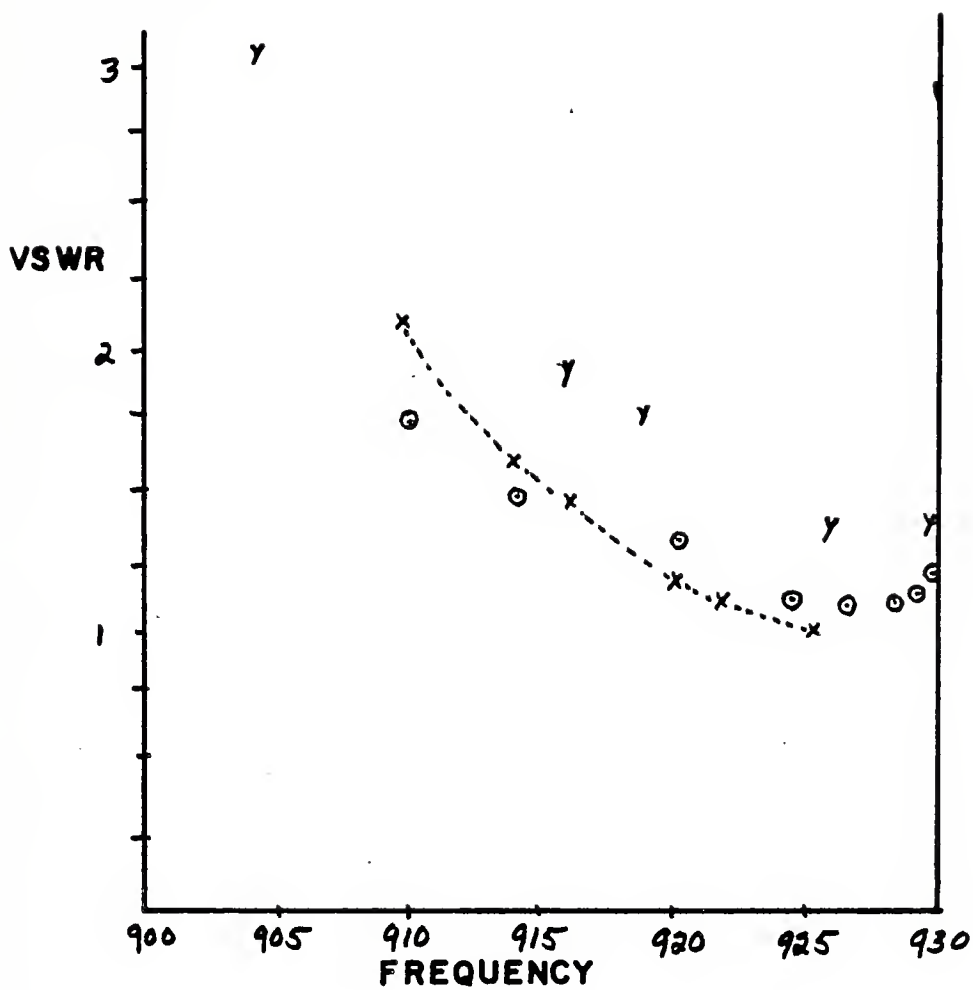$$R_{coax} = 45\,\Omega$$

$$(\sin y)\,99\,\Omega = 45\,\Omega$$

$$y = 27^\circ$$

$$\ell\left(\frac{27^\circ}{90^\circ}\right) = y_1 = \underline{0.51b\ in.}\ (\text{initial})$$
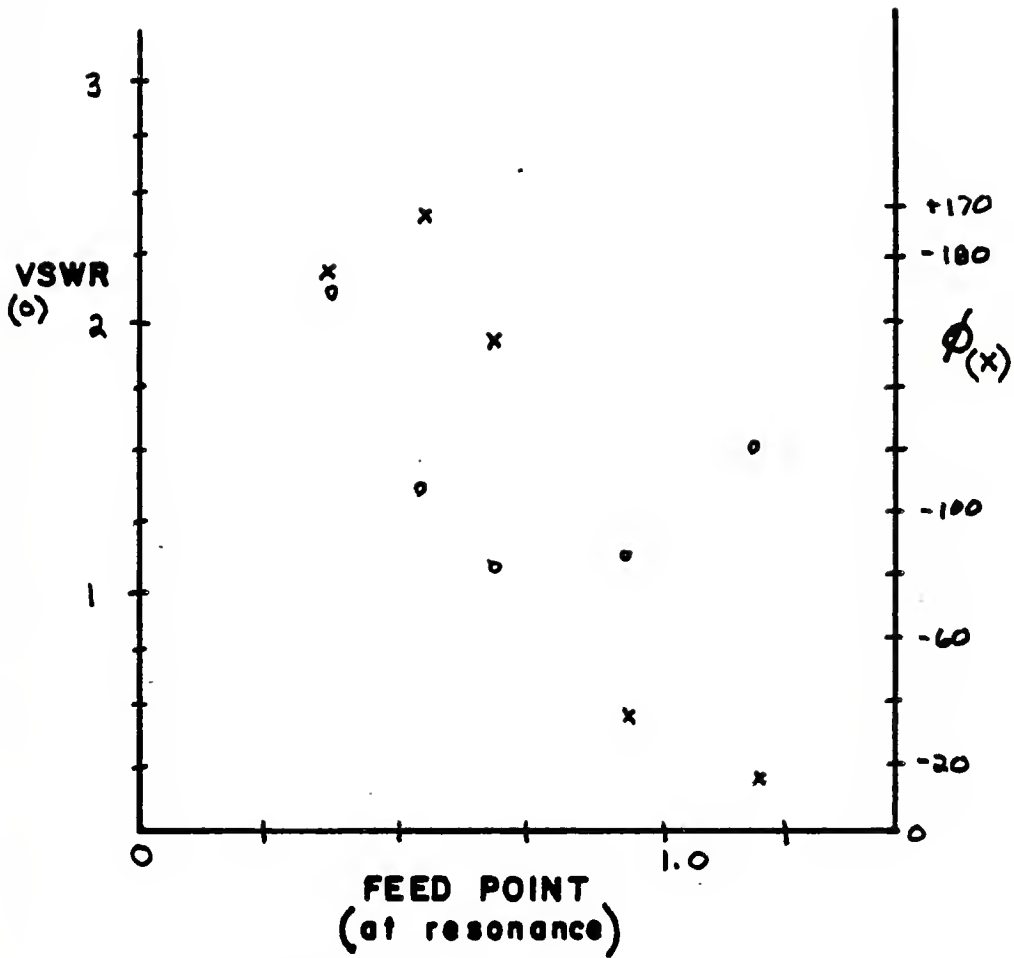
$$R_{in}\,(\text{actual}) = 72\,\Omega$$

$$y_1\,(\text{actual}) = \underline{\underline{0.85\ in.}}$$

Figure 14 —   SLOT IMPEDANCE BEHAVIOR

32

Figure 15 - VSWR VS FREQUENCY

Figure 16 - VSWR VS FEED POINT LCCATION

optimum feedpoint of 0.85 inches is indicated, or roughly 50 percent of the radius. By using the voltage reflection coefficient, the feedpoint and cable resistance, one can calculate the load resistance seen by the radiating element. The reflection coefficient yields the resistance value seen by the cable input. This value can be extrapolated to yield the parallel load resistance of the element. This value times two gives the new slot resistance of the radiator. Typical values are summarized in figure 17 yielding an average slot resistance of 143.65 ohms. The fact that this value is an average taken at several feedpoint locations lends a certain amount of credibility to the assumed value. These calculations will become more important later when calculating aperture efficiency and the actual gain of this antenna. The data presented in figure 17 is by no means accurate since a pure resistive load was assumed, and no correction due to unknown reactive components was made. The results from figures 15 and 16 also indicate that a resonant frequency of 928 mhz was obtained with the 1.72 inch radius antenna; well beyond the 918 mhz frequency calculated earlier. Several other radiating disks were made (with increasing radii) and a resonant frequency of 920 mhz was finally obtained using a disk radius of 1.77 inches. Precision in the etching process was an inherent problem since a small error in the radius would lead to a large error in the resonant frequency at these high frequencies.

The theoretical slot resistance of the 1.77 inch radius disk was calculated to be 198.98 ohms, or a parallel input impedance of 99.49 ohms. A reflection coefficient of 0.12, a VSWR of 1.27 and a half power bandwidth of 17 mhz was measured at a feed point of 0.85 inches. This yielded an approximate input impedance of 83.63 ohms, or a slot impedance of 167 ohms. The theoretical gain, using a formula from reference 9 shown below, was calculated to be 3.59, or 5.55 db. The radiation resistance of a short

FEED POINT (inches)	K_r	R_{in}	R_a
0.40	-0.367	79Ω	158Ω
0.55	-0.165	67Ω	134Ω
0.70	-0.08	64Ω	128Ω
0.90	+0.081	72Ω	144Ω
1.20	+0.201	76Ω	152Ω
	AVE.	72Ω	143Ω

K_r REFLECTION COEFICIENT

R_{in} INPUT IMPEDANCE

R_a SLOT IMPEDANCE

Figure 17 -   SLOT IMPEDANCE CALCULATIONS

dipole is shown below, and was calculated to be 14.96 ohms.

$$G_o = \frac{4\pi \ area}{\lambda_d^2}$$

$$\lambda_d = \lambda (\epsilon_r)^{1/2}$$

$$R_{rad} = 20\pi^2 \left(\frac{dl}{\lambda_o}\right)^2$$

The impedance matching efficiency is equal to the transmission coefficient , or one minus the reflection coefficient, equal to 0.88. The aperture efficiency is calculated below.

$$\ell_a = 1 + \frac{14.96 - 83.63}{14.96 + 83.63} = 0.304 \ (30.4\%)$$

The overall efficiency is the product of the two, or 0.2676 (26.76 percent). The actual gain is the product of the overall power efficiency times the theoretical gain, or 0.960 (minus 0.173 db). One has to remember that this actual gain is the product of expected theoretical gain and power management (i.e. impedance matching and aperture efficiency).

The quality factor, Q, for a dielectric sandwich material is equal to the reciprocal of the loss tangent. The expected bandwidth for this type of circuit is then the resonant frequency divided by the quality factor. The specification given by the manufacturer for this material's loss tangent, or dissipation factor (D), is 0.02. This yields a Q of 50 and an approximate bandwidth of 18.4 mhz. Results from a Vector Voltmeter experiment indicate a bandwidth of 17 mhz between the half power points. The half power points are those VSWR readings on either side of the resonant frequency that yield a reading of twice the resonant VSWR reading.

C. EXPERIMENTAL RESULTS

Figures 18 and 19 show the elevation and azimuth antenna radiation patterns for this antenna. It can be seen that the half power azimuth coverage is 95 degrees and the elevation coverage is approximately 120 degrees. This yields a maximum directive gain of 3.61 (5.58 db). The maximum directive gain times the power efficiency equals a gain of 0.968 (minus 0.14 db). This is approximately a one percent error from the theoretical gain calculated earlier. The antenna field patterns of both the Beanie and disk antennas were compared and the maximum gain of the Beanie antenna was found to exceed that of the circular disk by about 1 db. Thus even though the low profile, circular disk antenna should have a theoretical gain much higher than the Beanie, poor impedance matching and primarily poor aperture efficiency causes the overall antenna gain to be lower than a quarter wave monopole (Beanie) antenna.

Aperture efficiency is a function of the radiating disk input impedance and the characteristic radiation resistance of the antenna. When the length of the dipole becomes smaller in comparison to its freespace wavelength, then the aperture efficiency will decrease due to the inability to match the input impedance to the radiation impedance. This is the reason why a multiple feed, rectangular microstrip antenna is so much more efficient, because it allows the designer to increase on side length to the point where the radiation resistance does not become so small that an appropriate impedance match cannot be made. The width of this antenna is governed by the frequency and the dielectric constant of the material. The rectangular microstrip antenna has a similar radiation pattern as the circular disk, but with a higher aperture efficiency and therefore the gain achieved is much higher.
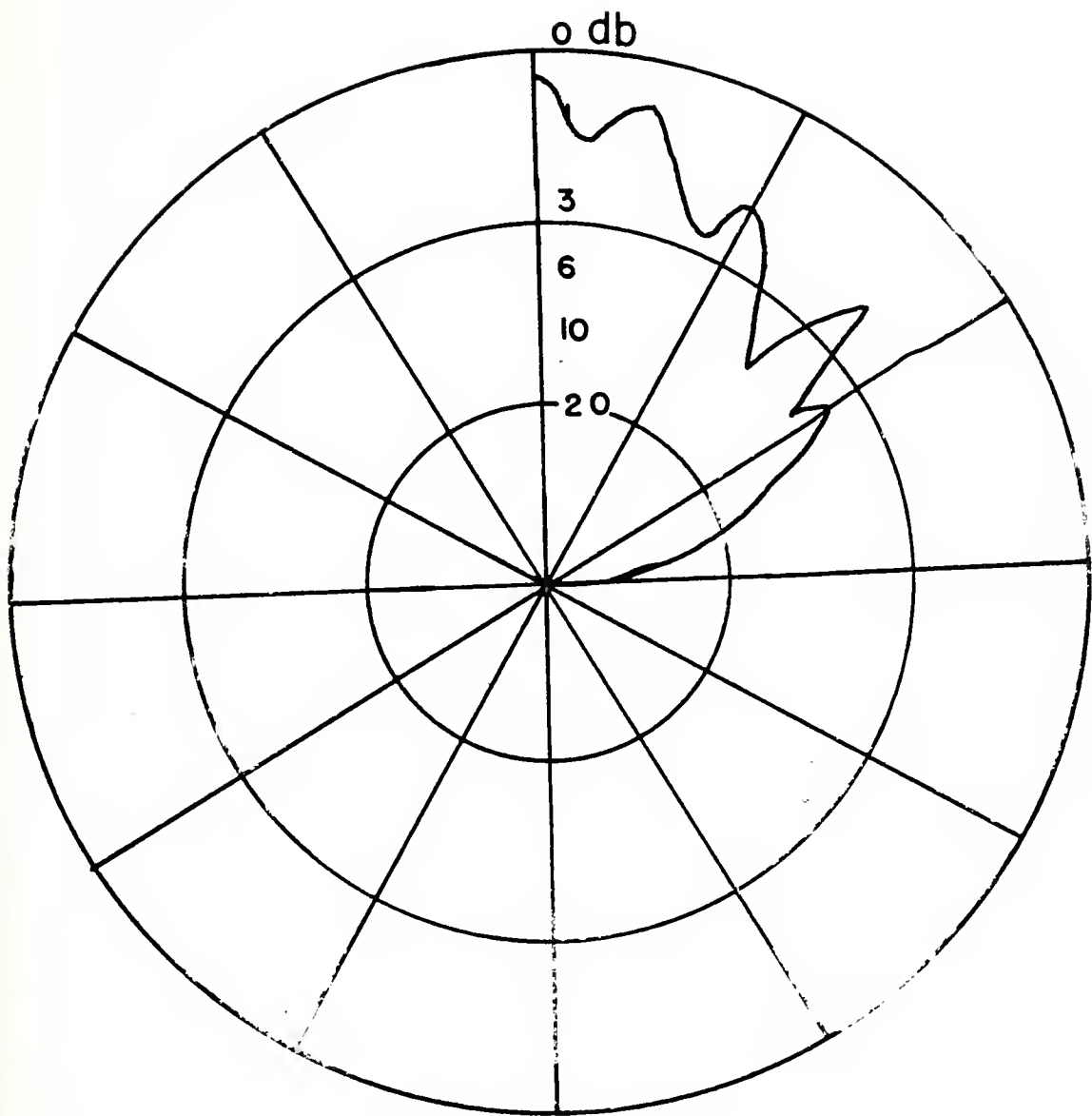
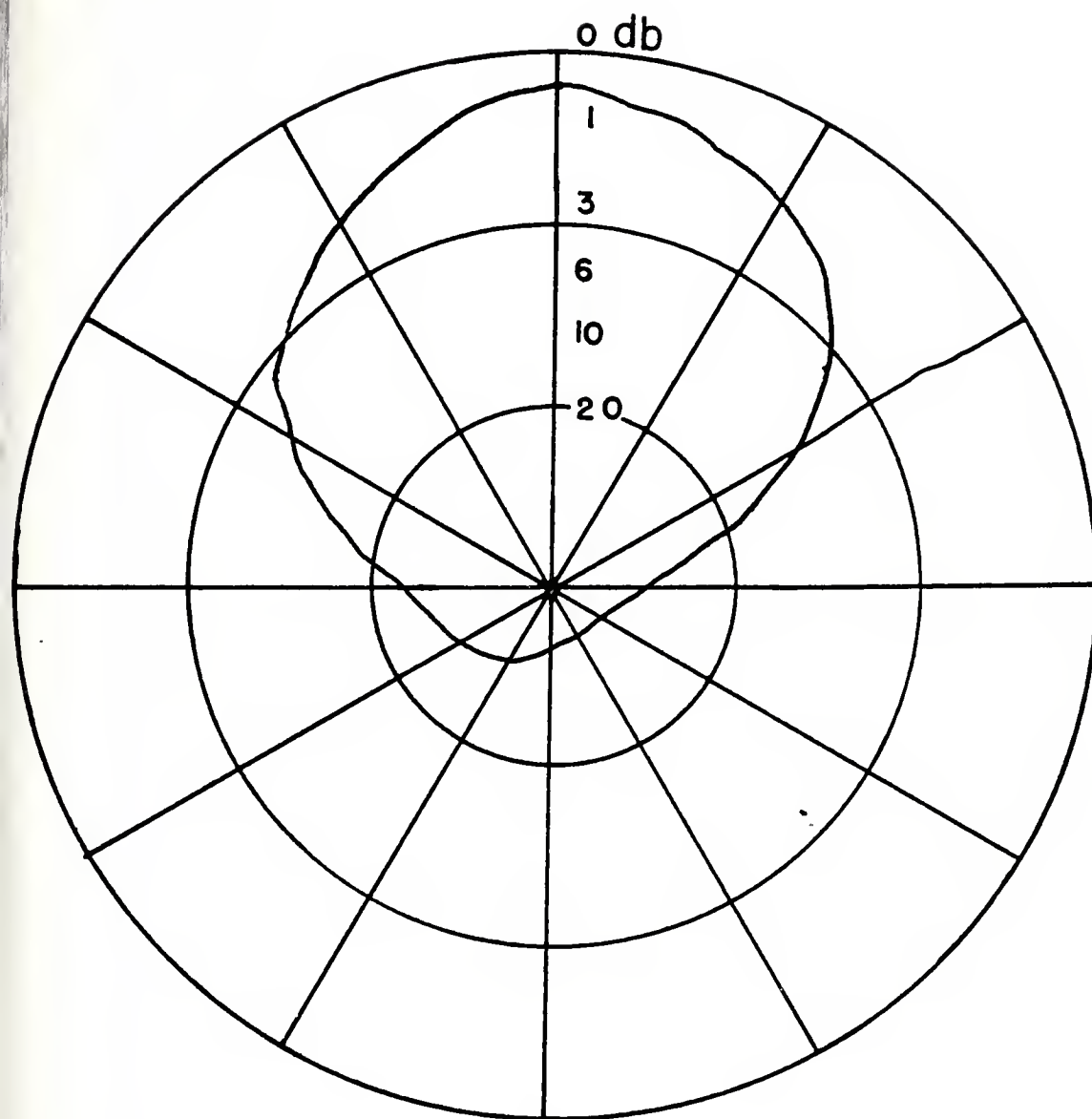Figure 18 - ELEVATION ANTENNA PATTERN

Figure 19 - AZIMUTH ANTENNA PATTERN

It should be noted that in the antenna radiation pattern tests, several antenna alignments were tested. That is, the maximum gain was attained when the antenna surface was parallel to the transmitting antenna (monopole), with the feed point and center short vertically aligned (thus giving vertical polarization). When the feed point-center short alignment was rotated 90 degrees (simulating horizontal polarization), the antenna gain was reduced by over 10 db (or effectively no reception). When the antenna surface was perpendicular to the vertical monopole the received gain was again minimal. The ground plane was reduced to the same diameter as the radiating disk with the same results. These radiation pattern tests crudely show that the E-field lines of force approximated in an earlier figure are in fact basically correct. It should be noted that no allowance was made for the effects due to the center short or the coaxial feed and the effects that these may introduce. It was shown that there is a general weakening of the fields on the sides of the antenna probably due to the cancellation effects of the center short and the feed.

A new antenna was constructed with a radius of three times the half wave length radius previously calculated. The reason for this construction was that it would increase the radiation resistance while lowering the antenna impedance so that a better efficiency would be realized. It was also suspected that any radius of an odd number of half wavelengths would sustain this mode. When the antenna was tested with the Vector Voltmeter, it was found to exhibit a VSWR in excess of 12. This indicates that the mode was not sustained and that losses due to other modes prevailed.

IV. CONCLUSIONS AND RECOMMENDATIONS

From the results of the experimentation section and theory, it is felt that this antenna design is not suited as a solution for a replacement antenna for the RMS system. A single element, circular disk, lowprofile, microstrip antenna cannot, at any frequency, attain a suitable aperture efficiency sufficient to maintain a high theoretical gain. The radiation resistance of a high dielectric constant material radiator is just too low to effectively match the high input impedance exhibited by this type of antenna. The antenna pattern coverage of this disk element is also unsuited for the RMS range configuration. If a rectangular wraparound antenna were constructed, the aperture efficiency could be increased significantly, but at 918 mhz the feed network would be too large to allow the antenna system to be mounted on a battle helmet. A wraparound antenna could be mounted on a cylinder for large vehicles, but the problem of survivability against trees, etc. in a field environment would still be a problem. The cost of such a cylindrical antenna would probably be prohibitive if there were many vehicles in the range area.

The recommendation for an improved antenna system would be to: 1) Improve the efficiency of the Beanie antenna, and 2) Replace the A-station antennas with a rectangular multiple feed antenna wrapped around a cylinder. By having each feed alternate by a 90 degree phase shifter, both horizontal and vertical polarization can be achieved to solve the problem of reception when the soldier is in the prone position. This type of antenna arangement would allow improvements in the following areas: 1) higher overall gain,

2)   Vertical/horizontal   polarization   coverage,   3)
Omnidirectional coverage,   and 4) Lower overall system cost
by only replacing the A-station antennas instead of all the
B-station antennas.

If the phased cylindrical array is not feasible, then a
basic cylindrical antenna could be constructed with a
separate planar antenna rotated 90 degrees so that the
horizontal polarization could be realized. This procedure
might be cheaper in the long run since a flat antenna is
cheaper to construct, and the phased matched network of the
cylindrical antenna would be avoided.

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